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STRENGTH RESERVES IN USSR MACHINE CONSTRUCTION

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It has already been pointed out (Vestnik Mashinostroyeniya, No 11-12, 1943, pp 6-16) that the technological processes of machine building can provide an increase in the strength indexes of machine construction materials and, consequently, a fuller utilization of them. It must be emphasized that the basic means for further increase in the endurance of the product involves the use of the plastic deformation and internal stresses which arise in almost every technological process.

In the casting industry, not introducing any new alloys, the endurance of cast products can be significantly increased by regulating the internal stresses in them.

The most essential possibility of increasing the strength of steel by forging and rolling is the close control of finishing temperature for these operations. Finishing them at relatively low temperatures in the range of Ar_3 - Ar_1 or even lower can significantly increase the indexes not only of static strength but of cyclic strength.

The strength indexes of welded seams made automatic by electric-arc welding under flux are incomparably higher than those of seams made by hand electric-arc welding.

Cold working by cutting brings important changes into the surface layer of the part which greatly influence the strength of the part as a whole. Therefore, the establishment of cutting parameters should be based, in a number of cases, not only on economic considerations but also on requirements applied to the part from the viewpoint of its reliability.

Finally in heat treating, done to impart definite strength characteristics to the part, merely controlling the physicochemical and structural changes in the metal frequently does not lead to the desired results. The success of heat

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treatment of the part cannot be considered fully attained if only the necessary structure is obtained in metals. It is necessary that this structure be accompanied by optimum internal stresses. Only then will the maximum strength of the part be attained.

However, technological possibilities for increasing the strength of machine construction materials are not limited to these examples. Strength resources in machine construction are significantly greater in the field of technology as well as in the construction field. Some of these reserves will be considered below.

Strength at High Temperatures

The problem of high-temperature strength is highly significant in machine construction. The search for creep-resistant steels and alloys is being conducted effectively in all countries. At the same time, the strength possibilities of recognized types of structural steel are not being fully utilized.

The graphic results of creep testing of molybdenum steel may be taken as an example. On the ordinate axis were dotted the stresses producing a one-percent deformation over a period of 100,000 hours; abscissas represented temperature. Each of the curves relates to a molybdenum steel with a definite grain size shown by the ASTM number (2 to 8) for each curve. It is evident that for each temperature there is an optimum gain size which assures the best creep resistance. Let us examine the creep resistance of a molybdenum steel at a temperature of 540 degrees, which is of great interest at the moment to power-machine constructors. It is not difficult to see that a rate of creep of 10^{-5} percent per hour can cause a stress of 10 kilograms per square millimeter if the steel grain number is 3, and about 2 kilograms per square millimeter if the grain number is 8. It is clear that the first of these steels (No 3) can be used in turbine construction with working temperatures of 540 degrees, while the second would not be good at the indicated temperature. Metallurgists have not yet prepared a steel with a rigid grain-size specification. Consequently, machine constructors are not in a position to utilize fully the strength properties of molybdenum steel at high temperatures. This is definitely a strength reserve.

The results of creep testing for three steels which have fairly similar compositions were plotted on a graph. One of them was prepared in the acid open-hearth furnace, the second was made by the basic open-hearth method, and the third in the basic electric furnace. These results show that the method of preparing the steel has a substantial influence on its creep resistance. The best of them is the basic steel, especially the one made in the electric furnace. However, this possibility also is not widely employed by metallurgists, even though it offers a very significant strength reserve.

The relaxation of two types of steel was studied -- low carbon steel with 0.15 percent centigrade and medium carbon steel with 0.8 percent centigrade -- depending on the original structure. It must be noted that high relaxation resistance generally conditions high creep resistance. Therefore, these results of the relaxation tests have a much greater significance. They indicate the great influence of the original structure of the steel on the relaxation process (and consequently on creep). It must be noted that the least durable in the relaxation process is the sorbite structure, and the most durable structure is the lamellar pearlite. It is a well known fact that steel with a sorbitic structure is used most often for construction parts, while steel with a lamellar pearlite structure is rarely employed;

i.e., the direct opposite of what should be used. It appears also that a low-carbon steel at high temperatures is most resistant if it has large grains; at lower temperatures, fine-grained steel is preferred. These interesting facts also reveal a strength reserve for machine construction.

Surface Strengthening of a Metal

Surface strengthening of a metal by carburization (cementation), nitriding, heating with high-frequency currents followed by rapid quenching (high-frequency hardening), and cold hardening the surface by way of shot blasting or roller burnishing, are widely known. However, the results obtained by these operations are extremely varied. Therefore, it is natural that constructors, unable to depend on the stability of these technological processes, design the parts according to the lowest strength indexes. Such losses are very considerable. By burnishing, the cyclic strength can be raised from 100 to 120 - 250 units.

The high-frequency process sometimes does not increase the cyclic strength of the part and at other times raises it 100 percent and more as compared to the initial state. Even established operations such as nitriding and cementation show a rather large variance in the results of strength determination. Such a variance is explained by operations which are not fully developed or by inadequacies in the precision of technological operations.

The results of measuring the fatigue limits in the bending and twisting of various materials after shot blasting show how little developed is the indicated process, and how greatly the data for very similar types of steel vary because of this. For example, in the case of two very similar steels, the increase in the endurance of one is 27 percent while for the other it is 11 percent. For other types, this difference is even greater.

From what has been said, it follows that the strength of the part can be increased significantly by a more detailed development of the technological processes and the development of more precise ways of conducting them.

The strength of the part, especially cyclic strength, is sometimes lowered very much by construction factors. This is illustrated by the data tabulated below. The tensile strength is taken as the 100-percent index. Depending on the type of steel, the fatigue limit in bending is 55 to 75 percent of the ultimate strength. The fatigue limits were established for smooth samples with a comparatively small diameter (10-15 millimeters). The fatigue limits (endurance) of the parts, prepared from the same types of steel, are indicated as percentages of the ultimate tensile strength.

Object	Fatigue Limit (in % of ultimate tensile strength)
Aircraft engine crankshaft (journal diameter 80 mm)	10.5
Diesel crankshaft (journal diameter 24.5 mm)	7.0
RR car axle with pressed wheel (d equals 190 mm)	12.2
Straight shaft with pressed hub (d equals 40 mm)	20.0
Straight shaft with spline-fixed hub (d equals 30 mm)	13.6
Gear wheel	9.0

Object	Fatigue Limit (in % of ultimate tensile strength)
Threaded bolt (d equals 1 1/8 in)	7.5
Bolt joint of two No 20 I beams	6.8
Welded joint of two No 20 I beams	11.2
Riveted joint of plate	21.4
Welded joint of plate (cross sectional area F equals 2,660 sq mm)	24.0

It is obvious just how great the losses in cyclic strength in the parts are in comparison with the endurance of laboratory samples. The question arises whether these losses are avoidable and whether they can be eliminated or reduced. If they are unavoidable, then ways for their elimination need not be sought; if they are avoidable, there is a strength reserve of significant value.

The significant drop in the index of cyclic strength is explained by two effects: (a) the scale factor, and (b) stress concentration.

The scale factor has been studied, but not to a degree commensurate with its significance. However, there are two criteria which we can use. One of them, Leyer's, establishes a decrease in the fatigue limit almost by half with an increase of the diameter of the part from 10 to 200 millimeters. The second criterion, Peterson and Faul'gaber's, limits this decrease by a maximum of 20 percent. Not dwelling here on the causes of the scale factor (they are still very questionable), it must be noted that most constructors, as long as a solution is not found, will use the lower curve (Leyer's) in their calculations as the more reliable one, whereas experimentally accumulated data responds more to the upper curve. Consequently, the difference in the ordinates of both curves is a strength resource and it should be utilized as soon as possible.

Stress concentration in the part can be eliminated in various ways. One of these, which is very effective, infers that for a part with a form that brings about stress concentration, a metal is used wi a high index of the coefficent of sensitivity to notching

$$\gamma - \frac{E\Delta_w}{\sigma_w}$$

where E is the modulus of elasticity, Δ_w the cyclic toughness, and σ_w the fatigue limit at tension-compression.

Stress concentration can be lowered effectively by selecting material with low sensitivity to notching (or with high cyclic toughness). In practice, however, this is not done because cyclic toughness has been studied very little. The accumulation of data on the cyclic toughness of machine construction materials will permit utilization of these very great strength resources.

Unsolved Problems of Metal Strength

To a great degree, the development of contemporary machine construction is limited by unsolved problems of metal strength. Modern gas and steam turbines, automobiles and aircraft engines, steam locomotives, electric locomotives, and the like could be significantly improved if the constructors could increase the allowable stress in improtant units.

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Demands of machine constructors will stimulate the development of new alloys with higher strength indexes. However, the development of machine design cannot be based only on the creation of new, more perfect alloys. It is still necessary to combine the use of existing machine-construction materials with maximum efficiency.

The possibilities for machine constructors are not limited by the examples cited. A thorough study of the problems of strength in all its ramifications is the actual problem to be solved and that will bring worthwhile results. Machine constructors should learn to establish exactly the actual stresses in the machine parts, and quickly and reliably determine the actual stress distribution in the parts by calculating not only elastic deformations but plastic deformations as well. Machine constructors should develop new strength characteristics for metals which would be more exactly reflected in the behavior of the metals in service. They should know how to establish the change of strength characteristics and stress distribution under operating conditions which cause in the metal internal processes of a physicochemical nature. Machine constructors should be able to determine the influence of technological processes on strength indexes and to develop technological processes with respect to increases in the strength indexes. These are some of most urgent problems of machine construction. For example, the solution of the problems of static strength (a complex stressed state, brittle tensile strength, etc.) will permit an increase of the working stresses by 30-50 percent. The solution of a series of problems on cyclic endurance will allow an increase of the design stresses by 2-3 or more times, and in relation to the relaxation and creep of metal by 4-5 and more times.

The time for establishing various strength characteristics varies considerably. The time to determine the characteristic of static strength amounts to minutes (or tens or hundreds of minutes); the determination of fatigue strength requires hundreds of hours; and for creep and relaxation tests the time is expressed in thousands of hours. Consequently, factors which assure a great increase of design stresses also require greater consumption of time to establish the strength characteristics.

Finally, examination of the relative extent of utilization of the methods for testing the strength of metals reveals a complete disproportionality. That method of testing metals which requires the longest period of time to establish strength characteristics and which promises the greatest increase in allowable stresses has not yet received proper attention. It is clear that here, also, there are very effective endurance reserves, the use of which can affect favorably the development of modern machine construction.

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